Examination Timetabling Automation using Hybrid Metaheuristics

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***Abstract*— The timetabling problem consists in the scheduling of a set of entities to a set of resources in a number of time slots, satisfying a set of constraints. In this paper, a hybrid algorithm for solving the examination timetabling problem is proposed. Our approach applies a two-phase procedure. The first phase, solution generation, applies a graph colouring heuristic, whereas the second phase (improvement) uses *simulated annealing* and *hill climbing* metaheuristics. The proposed algorithm uses feasible local search operators, restricting the exploration of the feasible solution space. For the simulated annealing procedure, the cooling rate is computed adaptively given a fixed execution time. The approach, tested on the public ITC 2007 data set, is generally efficient as it is able to achieve comparable results with those of the ITC 2007's finalists.**

Keywords: Examination Timetabling, Graph Colouring, International Timetabling Competition 2007, Metaheuristics, Simulated Annealing.

I. Introduction

In timetabling, we aim to schedule a set of events (lectures, exams, surgeries, sport events, or trips) to a set of resources (teachers, exam proctors, nurses, medical doctors, referees, and vehicles) over space (classrooms, examination rooms, surgery rooms, and sport fields), in a prefixed period of time. For instance, in the *examination timetabling problem* (ETP) [2], the goal is to allocate exams (and their enrolled students) to exam proctors over time periods, while assigning each group (exam proctors, students attending an exam) to the available rooms. Additionally, a set of hard and soft constraints, are considered. The hard constraints must be fulfilled to achieve a feasible timetable. Regarding the soft constraints, there's no obligation to fulfill them; thus, violations of these may occur. However, one aims to minimise these violations.

In this paper, we propose a hybrid approach with heuristic and meta-heuristic algorithms to solve the ETP. This approach was tested on the public *International Timetabling Competition 2007* (ITC 2007) [5] data set, which comprises the state-of-the-art.

II. Proposed Approach

The proposed hybrid method, named hSA (*Hybrid Simulating Annealing*), has two phases, namely solution construction and optimisation. In the first phase, a graph colouring heuristic is used. In the second phase, two metaheuristics are used, namely *simulated annealing* (SA) and *hill climbing* (HC). The hSA parameters and their influence on the results are discussed in Section II-A. Sections II-B and II-C describe the hSA phases in detail.

A. Algorithm Parameters

The hSA parameters consist of the inner SA parameters, and also the time limit for which the algorithm is permitted to run. The time limit value was set according to the ITC 2007's rules. The SA has four parameters: T_{max} – the maximum/initial temperature; T_{min} – the minimum temperature; k – the number of iterations per temperature; $rate$ – the (automatically computed) cooling rate. The temperature is updated simulating the exponentially-decreasing function of time, of the temperature in metal annealing processes, defined as

$$T(t) = T_{max} \cdot \exp(-rate \cdot t), \qquad (1)$$

with $rate$ and T_{max} as defined above.

The T_{max} and $rate$ parameters are the ones which have the largest impact in the algorithm's outcome. Smaller $rate$ values provide for a more intense neighbourhood exploitation; the T_{max} should be large enough in order for the hSA to accept some non-improving solutions, allowing the algorithm to escape from local optima. T_{min} should be a small value, leading hSA to accept mostly improving solutions or accept solutions which have a small cost degradation. Usually, T_{max} has a large value as compared to $rate$, for instance $T_{max}/rate > 100$.

B. Solution Construction

The exams to be assigned to periods and rooms are split into four lists. Each list is sorted using the Largest Weighted Degree ordering criterion [2]. The resulting assignment lists (processed by the given order) are: 1) Unassigned examinations with the *Room Exclusivity* hard constraint; 2) Unassigned examinations with the *After* hard constraint; 3) Unassigned examinations with the *Examination Coincidence* hard constraint; 4) All other unassigned examinations. The examination with the highest priority is selected for scheduling, using two modes:

1) Normal – The examination is scheduled in the (period, room) values, chosen randomly from the set of feasible values; otherwise, the Forced mode is used.
2) Forced – In case the selected values are not feasible, the selected exam is scheduled in a random period

and room. All the conflicting exams are removed from the timetable and reinserted into the respective unassignment exam lists.

C. Optimisation Phase

In this phase, the SA and HC meta-heuristics are used. The SA cooling schedule *rate* parameter is automatically set (by running a simulation), in order for the SA to use the majority of the available time budget. Then, HC runs for the remainder of the available time. In this way, the rate value is computed automatically for each data set instance. Five neighbourhood operators, similar to the ones proposed by Müller [5], are considered: Room Change; Period Change; Period and Room Change; Room Swap; Period Swap.

III. Experimental Evaluation

The algorithm code, written in C# programming language, is publicly available at `https://github.com/devilsdante/isel-examtimetabling-2014-2015`. The experiments were conducted on an Intel Core i5 3570k 3.4 GHz Quad-Core (8 GB RAM) PC running Windows 7 Professional – 64 bit OS. The hSA parameters' values are: $T_{max} = 0.1$, $T_{min} = 1 \times 10^{-6}$, $k = 5$, $rate$ = automatically computed, *time limit* = 221 seconds. 20 executions were made on each ITC 2007 data set instance.

In Table I, we compare our approach with the finalists of the ITC 2007 [5], namely: Mul09 – Müller (2009), Gog12 – Gogos et al. (2012), Ats07 – Atsuta et al. (2007), Sme08 – De Smet (2008), and Pil08 – Pillay (2008). Table II reports the comparison with recent approaches of Rah14 – Rahman et al. (2014) [7], Bry14 – Bryce et al. (2014) [3], Mou14 – Mouhoub et al. (2014) [4], Bur14 – Burke et al. (2014) [2], and Abd14 – Abdullah et al. (2014) [1].

IV. Conclusions

In this work, a two-phase hybrid algorithm for solving examination timetabling problems is proposed. The approach uses a graph colouring heuristic in the first phase and metaheuristics in the second phase. The algorithm, tested on the ITC 2007 benchmark, against both the ITC 2007 finalists and recent work, shows promising results as well as room for improvement. Due to efficiency reasons, the proposed approach has two known shortcomings. The first one is a simplistic construction algorithm, which is unable to solve the most difficult instance (Instance 4); due to repetitive assignments of exams to the same set (period and room), it may yield a looping effect. The second shortcoming is to disregard coincident exams, restricting the algorithm exploration capability. In future work, we intend to integrate the Conflict Based Statistics data structure [6] in order to record exam conflicts and to prevent repetitive assignments. We also aim to improve on the proposed operators to move coincident exams.

TABLE I: Best solution's fitness for hSA and the ITC 2007 finalists. The best result is in boldface and the second best is underlined. "n/a" states that the corresponding instance was not tested or a feasible solution was not found.

Inst.	Mul09	Gog12	Ats07	Sme08	Pil08	hSA
1	**4370**	5905	8006	6670	12 035	<u>4857</u>
2	**400**	1008	3470	623	2886	<u>451</u>
3	**10 049**	13 771	17 669	n/a	15 917	<u>13 375</u>
4	**18 141**	18 674	22 559	n/a	23 582	n/a
5	**2988**	4139	4638	<u>3847</u>	6860	3965
6	**26 585**	27 640	29 155	27 815	32 250	<u>26 665</u>
7	**4213**	6572	10 473	5420	17 666	<u>4576</u>
8	**7742**	10 521	14 317	n/a	15 592	<u>8238</u>
9	**1030**	1159	1737	1288	2055	<u>1033</u>
10	16 682	n/a	<u>15 085</u>	**14 778**	17 724	19 858
11	**34 129**	43 888	n/a	n/a	40 535	<u>39 150</u>
12	<u>5535</u>	n/a	**5264**	n/a	6310	6109

TABLE II: Best solution's fitness for hSA and comparison with state-of-the-art approaches.

Inst.	Rah14	Bry14	Mou14	Bur14	Abd14	hSA
1	5231	5186	**4218**	6235	5328	<u>4857</u>
2	433	**405**	<u>420</u>	2974	512	451
3	**9265**	9399	<u>9335</u>	15 832	10 178	13 375
4	<u>17 787</u>	19 031	18 658	35 106	**16 465**	n/a
5	<u>3083</u>	3117	**2718**	4873	3624	3965
6	<u>26 060</u>	**26 055**	26 100	31 756	26 240	26 665
7	<u>10 712</u>	**3997**	<u>4181</u>	11 562	4562	4576
8	12 713	**7303**	<u>7360</u>	20 994	8043	8238
9	1111	<u>1048</u>	1050	n/a	n/a	**1033**
10	<u>14 825</u>	**14 789**	14 918	n/a	n/a	19 858
11	**28 891**	<u>30 311</u>	31 177	n/a	n/a	39 150
12	6181	**5369**	<u>5544</u>	n/a	n/a	6109

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